AQUACULTURE AND NUTRIENTS—DEVELOPING POLICIES FOR PROTECTING THE ENVIRONMENT OF PORT PHILLIP BAY

JOHN KOWARSKY

Strategic Policy Branch, Policy Division, Environment Protection Authority, 477 Collins Street, Melbourne, Victoria 3000

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Interrelationships between aquaculture and nutrients in Port Phillip Bay are explored in the context of the State Environment Protection Policy (The Waters of Port Phillip Bay). Approaches to protecting the beneficial use "production of edible shellfish without the addition of nutrients" from adverse effects of nutrient enrichment are discussed. It is concluded that a monitoring program for the early detection of algal blooms is essential to protect both public health and the aquaculture industry.

THROUGH its Aquaculture Initiative, the Victorian Government signalled its intention to facilitate the development of commercial aquaculture ventures (Victorian Government 1987a). Marine aquaculture, or mariculture, is of topical interest as a relatively new and expanding use of water in this State, and Port Phillip Bay is at present the site of almost all of Victoria's commercial mariculture. Nutrients are of great significance to the success of any aquaculture operation.

As the State Environment Protection Policy (SEPP) (The Waters of Port Phillip Bay) is at present under review, this is an opportune time to discuss some of the policy issues relating to the management of aquaculture within the Bay. In a more general sense, a discussion of the interrelation of the three subjects in the title of this paper should illustrate the Victorian Government approach to "protecting" Port Phillip Bay from pollution.

Before discussing how aquaculture and nutrients interrelate within the Bay, it is necessary to provide some background as to the way in which environmental policies have developed in Victoria.

THE CONCEPT OF BENEFICIAL USES

A "beneficial use" has been defined as "a use of the environment or any element or segment of the environment that is conducive to public benefit, welfare, safety, or health and which requires protection from the effects of waste discharges, emissions and deposits" (Section 4(1) of the Environment Protection Act 1970; Victorian Government 1987b). Examples of beneficial uses of water include (EPA 1983):

(a) potable water supply;
(b) agricultural water supply;
(c) industrial water supply;
(d) hydro-electric power generation
(e) navigation and shipping;
(f) recreation;
(g) production of edible fish and crustaceans;
(h) shellfish culture and harvesting;
(i) maintenance of aquatic ecosystems;
(j) maintenance of modified aquatic ecosystems;
(k) maintenance of water-associated wildlife;
(l) recharging of aquifers; and
(m) scientific and educational uses.

Under the above definition, use of the environment as a sink for discharge of wastes is clearly not a beneficial use.

Not all beneficial uses will apply to any given body of water, and some uses may exclude others; for example, use of water for a shipping channel may preclude its use for recreation.

Some beneficial uses may have the potential to lead to environmental degradation. For example, recreational boating activities may, in the extreme, lead to contamination of water by motor fuel, fumes, anti-foulants and human wastes. In general, however, the deleterious environmental effects of beneficial uses are relatively minor and short-term.

Each beneficial use of water has a suite of environmental indicators considered relevant for its protection. For example, the bacterial concentration of water is a relevant indicator for the beneficial use "swimming" but not for "industrial cooling". Each relevant indicator is given a level (an "objective") to be maintained or achieved to protect the beneficial use being considered. The objective is based upon published standards and research results. An attainment program outlines the mechanism by which environmental goals are to be achieved.

Deciding upon the beneficial uses of a given segment of the environment requires an assessment and balancing of the present status and use of that segment, its potential future use, and whatever environmental improvements can be realistically attained. Once an SEPP is declared, the Victorian Government is committed to protecting the defined beneficial uses against adverse effects of pollution.

SEPPs are policies of the Victorian Government and must be complied with by all organisations, including government bodies, and individuals.

THE STATE ENVIRONMENT PROTECTION POLICY—THE WATERS OF PORT PHILLIP BAY

This policy was declared in 1975. Port Phillip Bay is divided into nine segments (Fig. 1) and beneficial uses of the water of each segment are listed.

Aquaculture is not specifically listed as a beneficial use but would fall in one of the following two.

1. Production of fish and crustaceans for human consumption. This use is protected in all segments of the Bay except the Werribee segment.

2. Production of fish, crustaceans and shellfish for human consumption. This is a protected beneficial use only in the Exchange and Central segments of Port Phillip Bay. "Shellfish" is undefined but in this context could be taken to include bivalve and probably other mollusc groups.

For each of the segments the Policy gives the same general objective for the indicator "nutrients and biostimulants"; i.e. "Waste discharges shall not add nutrient substances or other growth stimulants in quantities sufficient to cause excessive or nuisance algal or other plant growth...". In addition, numerical objectives for total nitrogen, total phosphorus and chlorophyll *a* levels are specified and differ between segments.

In the recommended water quality criteria manual (EPA 1983), "nutrients" was not considered a relevant water quality indicator for the beneficial uses "shellfish culture and harvesting" or "production of edible fish and crustacea". This is an error, as biological phenomena related to nutrients in the water can profoundly affect aquaculture organisms and their human consumers.

Another SEPP, the SEPP (Waters of Victoria), declared in 1988, applies to all surface waters of Victoria except where varied by any SEPP separately declared.

TYPES OF AQUACULTURE

Aquaculture can be divided broadly into two categories.

1. *Active-feeding aquaculture.* The cultured organisms are provided with food, such as pellets or trash fish (e.g. caged salmon culture), or the environment is enriched by the application of fertilisers to provide for greater primary production (e.g. some pond culture of fish and crustaceans).

2. *Passive-feeding aquaculture.* The organisms rely wholly on naturally occurring food, usually by filter-feeding on phytoplankton (e.g. mussel farming). No food is provided directly or by the addition of inorganic nutrients to stimulate primary production.

ENVIRONMENTAL EFFECTS OF AQUACULTURE

A comparison of the environmental effects of active- and passive-feeding aquaculture with regard to nutrients has been made by Gowen et al. (1988), Folke & Kautsky (1989) and Woodward (1989).

The nitrogen budgets of a salmon cage farm and a mussel long-line farm are very similar; in both cases about 75% of the nitrogen in the food supply forms either solid or soluble waste (Folke & Kautsky 1989). The fundamental difference between the two is that in the case of the salmon farm the food supply is added, and there is a potential for hypernutrification which in turn may lead to eutrophication (Gowen et al. 1988). By contrast, there is evidence that mussel farming may lead to nutrient reduction (Kaspar et al. 1985).

It is possible to gauge the extent to which salmon and mussel farming activities may affect the nitrogen budget of a waterbody. For the purpose of this exercise assume that for each species an annual crop of 500 tonnes net weight of product is harvested. In the case of salmon, this is approximately equivalent to 12.8 tonnes nitrogen (assuming that 16% of wet weight is protein and that 16% of protein is nitrogen). From the relationship given in the previous paragraph, it

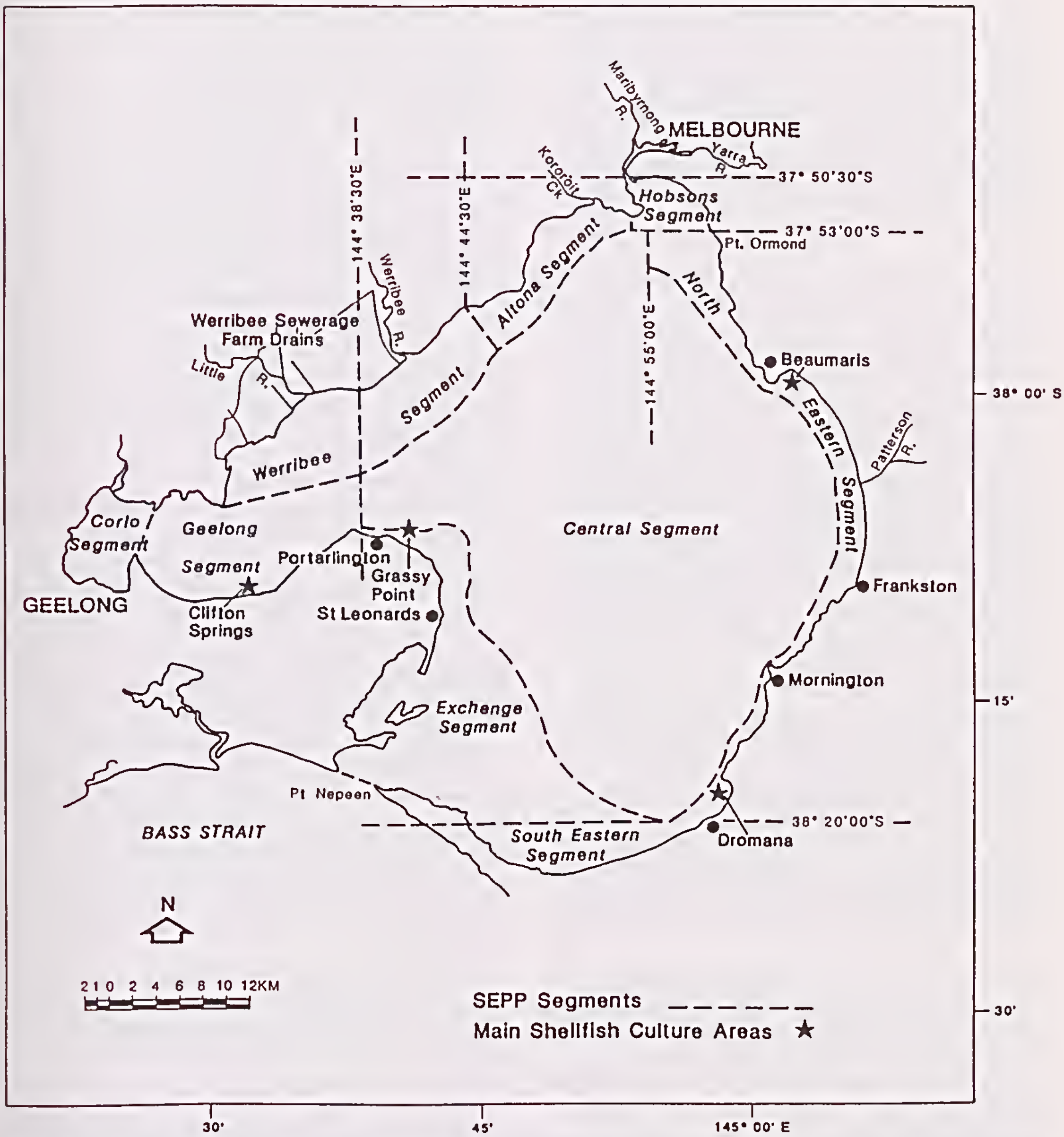

Fig. 1. Map of Port Phillip Bay showing segments defined in the SEPP (The Waters of Port Phillip Bay) (1975) and the approximate positions of main shellfish culture areas.

follows that about 3 times this amount of nitrogen, or 38 tonnes, from the added food supply remains in the ecosystem. In the case of mussels, removal of 500 tonnes wet weight is approximately equivalent to taking 4 tonnes nitrogen from the ecosystem (relationship of live weight:total N weight from Rodhouse & Roden 1987).

Mussel farming may, through a high rate of excretion of ammonium by the mussels, lead to an increased rate of nitrogen cycling in the water column (Kaspar et al. 1985, Rodhouse & Roden 1987). This could lead to an increased frequency of phytoplankton blooms around mussel farms, but this has not yet been observed (Rodhouse & Roden 1987).

In both types of aquaculture the solid waste will result in increased sedimentation underneath the farms (a salmonid farm may produce about 15 times more sediment than a mussel farm of similar size); however, in the case of passive-feeding aquaculture the increase under the farm is compensated by a decrease in sedimentation of surrounding areas (Folke & Kautsky 1989).

AQUACULTURE ACTIVITIES IN PORT PHILLIP BAY

Apart from a few small-scale proposals for experimental cage culture, aquaculture in Port Phillip Bay has been exclusively of the passive-feeding type, involving filter-feeding molluscs. Two relatively large commercial aquaculture zones have been established at Clifton Springs and Grassy Point, and a number of other small experimental leases have been set up around the Bay (Fig. 1). Significant aquaculture activities are thus taking place in a number of segments outside of the two in which shellfish production for human consumption is listed as a beneficial use in the current policy.

The main species of commercial interest is the blue mussel, *Mytilus edulis planulatus*; there is also limited interest in the flat oyster, *Ostrea angasi*.

Currently commercial shellfish production from mussel farms in the Bay is less than 1000 tonnes per annum; projections for future production extend to between 2000 and 3000 tonnes per annum over the next five years (D. Buckmaster personal communication 1990).

INTERACTION OF AQUACULTURE ACTIVITIES WITH NUTRIENTS IN PORT PHILLIP BAY

In considering aquaculture in the context of the nutrient status of Port Phillip Bay, three questions are pertinent.

1. Is there adequate nutrition available for filter-feeding shellfish?

That a commercial mussel farming industry has been established in the Bay provides some evidence that this is in fact the case. However, information on the maximum "carrying capacity" of areas of the Bay for mussel farming is not yet available.

Experimental growth trials using flat oysters have indicated that sites within Port Phillip Bay are amongst the best in Victoria for growth of this species.

A scallop (*Pecten alba*) fishery operates in the Bay, albeit with extreme fluctuations in population numbers in some years.

There is thus a reasonable case to consider aquaculture as having at least some potential as a beneficial use in Port Phillip Bay.

2. What would be the impact of commercial aquaculture on the nutrient status of the Bay?

If cultured mussel production in the Bay reached the upper projected figure of 3000 tonnes per annum, this harvest would remove about 24 tonnes of nitrogen annually from the Bay.

Were salmon farming to take place in the Bay, an annual production of 1000 tonnes live weight would be a realistic achievable upper limit for the medium term. This production would result in approximately 77 tonnes of nitrogen being added to the Bay each year.

The annual nitrogen load of Port Phillip Bay from all sources is well over 5000 tonnes.

3. What nutrient-related phenomena may have an impact upon aquaculture?

A number of species of phytoplankton, predominantly dinoflagellates, are known to produce various toxins including paralytic shellfish poison (PSP), diarrhetic shellfish poison (DSP), neurotoxic shellfish poison (NSP) and amnesic shellfish poison (ASP), each of which can cause serious illness and sometimes death in human consumers of shellfish so affected. The effects of algal blooms on shellfish have been comprehensively reviewed by Shumway (1990).

The exact relationship between the level of nutrient enrichment of the waterbody, and the type and extent of algal bloom which may occur, is not known.

In addition to toxins affecting human consumers of shellfish, algal blooms can cause mass mortalities of shellfish either through toxic effects or through reduction of dissolved oxygen levels.

Over recent years, two events have been recorded which have been of particular relevance to shellfish culture activities within the Bay.

(a) Bitter tasting shellfish. An extremely bitter taste was acquired by mussels (both cultivated and wild-caught), flat oysters and scallops throughout Port Phillip Bay during September 1987, and continuing through until about mid 1988 (bitter tasting mussels also occurred at a mussel farm at Flinders in Western Port in September 1987; this outbreak of "bitter taste" was less severe than that in Port Phillip Bay). Commercial crops of mussels became unsaleable as a result. Both natural and farmed shellfish stocks also suffered abnormally high mortalities. An investigation strongly suggested that a bloom of the diatom *Rhizosolenia chunii* was responsible for the bitter taste and subsequent mortality. There was anecdotal evidence of a "bitter taste" outbreak in mussels from Port Phillip Bay in the mid-1970s (Parry et al. 1989).

(b) "Red tides" (information from G. Arnott 1992, unpublished observations). Discolouration of the water in northern parts of Port Phillip Bay was reported in early January 1988, and investigations confirmed the occurrence of Victoria's first recorded "red tide". The alga concerned, *Alexandrium catenella,* was known from overseas work to be capable of contaminating shellfish with a PSP. During the bloom, mussels from certain parts of the Bay contained six times the USFDA limit of PSP. The bloom lasted for about 10 weeks but was always confined to the Hobson's Bay area of Port Phillip Bay. A public health alert warned people not to eat any shellfish from a defined area. No legal commercial supplies of shellfish being sold through retail outlets and restaurants were affected, and no toxins were found in mussels from any commercial or experimental mussel farm in the Bay. In April 1991 and January 1992 (when PSP levels far in excess of those found in 1988 were measured) similar blooms were observed in the northern part of the Bay, and public warnings were again issued.

Several species of toxic dinoflagellates and a toxic diatom are known to occur in Port Phillip Bay. A Port Phillip Bay Biotoxin Surveillance program has been conducted to protect public health from future outbreaks of toxic algal blooms.

AQUACULTURE AS A BENEFICIAL USE IN PORT PHILLIP BAY

Given that active-feeding operations contribute quantities of nutrients into the water, and that concern has already been expressed about the possibility of excess nutrients in the Bay, it may be decided that active-feeding aquaculture should not be considered a beneficial use anywhere within the Bay. Because such activities could be included within the present beneficial use "Production of fish and crustaceans for human consumption", it may be appropriate to rephrase this beneficial use to "Fishing for fish and crustaceans for human consumption".

On the other hand, in the context of nutrients in Port Phillip Bay, there is a strong case that passive-feeding aquaculture should be considered a beneficial use.

The beneficial use "Production of shellfish for human consumption" is not sufficient to define passive-feeding aquaculture, as certain shellfish species (for example, abalone) may be grown using active-feeding techniques. Rephrasing the description to "Production of edible shellfish without addition of nutrients" would better describe this form of aquaculture.

The selection of areas or segments of Port Phillip Bay in which passive-feeding aquaculture should be a beneficial use will depend upon consideration of several aspects of water quality—for example, the potential for metallic and bacterial contamination—in addition to the nutrient status. Not all segments will thus be suitable. While in no areas of the Bay could passive-feeding aquaculture be excluded at present on the grounds of unfavourable (and more specifically excessive) nutrients adversely affecting shellfish, given that the northern portion of the Bay has been affected by "red tides" in recent times, there may be some reservations about listing passive-feeding aquaculture as a beneficial use for this area.

PROTECTING THE BENEFICIAL USE "PRODUCTION OF EDIBLE SHELLFISH WITHOUT THE ADDITION OF NUTRIENTS"

The most difficult part of this exercise is to determine what are the relevant water quality indicators, and what particular objectives should be set to protect this beneficial use. We need to protect:

(a) the shellfish to ensure adequate survival, growth and reproduction; and

(b) the human consumer of the shellfish to minimise the health risk associated with eating the product.

Protection of the shellfish themselves will be in large part accomplished by the setting of water quality objectives for the beneficial use "Maintenance and preservation of natural aquatic ecosystems and wildlife" which is listed for most segments of the Bay. In any case, water quality criteria for protecting the human consumers of shellfish are likely to be as stringent as or more stringent than those for protecting the shellfish.

In the context of nutrients, protection of human consumers of shellfish will be afforded by protection against blooms of toxic phytoplankton.

Ideally, we would need to understand the relationship between phytoplankton blooms and nutrient levels in the waters of Port Phillip Bay in order to develop quantitative nutrient criteria. In examining historical records of red tides or toxicity episodes, we must be on guard for factors which may result in an apparent increase in the frequency of such events, such as increased knowledge and alertness by the scientific community, increased potential to detect toxicity due to close monitoring of shellfish farms, or inadequacy of past sampling techniques (Anderson 1989).

Even after allowing for the influence of the above factors in inflating estimates of the frequency of algal blooms, there is general consensus that these events, worldwide, are becoming more common, more severe, and more widespread. Nutrient enrichment is one of a number of factors thought to enhance algal blooms, and it has been established that there is a direct correlation between the number of red tides and the extent of coastal pollution (particularly from sewage and some forms of industrial wastes; Anderson 1989, Shumway 1990). In view of these findings, it is appropriate that we exercise caution in developing policies for nutrient management, even if we have no clear evidence of cause and effect with regard to nutrient levels and algal blooms in Port Phillip Bay.

Our level of understanding, in common with that elsewhere, still falls short of being able to predict phytoplankton events and the species "mix" when these occur. Until we can do so, a qualitative objective for the indicator "nutrients" such as that used in the SEPP (Waters of Victoria) may be the best we can do: "Waters shall be free of substances in concentration which cause nuisance plant growth or changes in species composition to the detriment of the protected beneficial uses."

To protect public health and the shellfish growing industry, it is essential that a monitoring program is in place to give early warning of unfavourable algal blooms. Shellfish harvesting can then be curtailed until the product is safe to eat. Measurements of nutrient concentrations and loads should also be made to understand better their relationship with the dynamics of algal blooms.

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